To Nordic or not to Nordic? *A different perspective with reason to appreciate Semitendinosus more than ever*

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Injury prevention | Hamstrings | Expert opinion

Headline

Vegemite or marmite, Messi or Ronaldo, Real Madrid or Barcelona, Nordics or no Nordics. These contentious debates continue to occur and will continue to occur for many years to come. But why Nordics versus no Nordics? Has there ever been a bigger debate about a single exercise? Has there been an exercise that has caused more arguments on Twitter or within a performance team as to whether they should be performed? The arguments around delayed onset muscle soreness (DOMS), the high volumes previously suggested and its non-functional nature continue to drive the discussions (1,2).

With a recent systematic review (3) demonstrating a 51% reduction in hamstring injuries with the simple addition of the Nordic hamstring curl (NHC), it is hard for many to argue against the favourable outcome-based data that NHCs' provide. It further supports previous work that demonstrated the significant reduction in hamstring injury in those adhering to a prescribed large volume NHC program (1).

Many researchers have since provided further reasons as to why NHC's may be of benefit (4–6). These have centred on the adaptations around hamstring architecture (fascicle length (FL)) and improvement in strength outcomes. Although this paper will touch on the 'quadrant of doom' parameters, the purpose of this paper is to appeal to your analytical, critical, theoretical and biomechanical mind as some possible reasons why the NHC can have such a vast impact on hamstring health. It is worth noting that this paper is reductionist in nature and no one exercise will be the saviour for hamstring injuries as all injuries are multifactorial in nature. This editorial will discuss the rationale for the NHC in performance sport. In addition, it will highlight the importance of semitendinosis (ST), its structure and function, and its adaptations thought to be important for hamstring injury prevention.

Semitendinosus Functional Anatomy

Structure and function are inherently related in the human body. For example, a ball and socket joint allows a higher degree of mobility, as opposed to a hinge joint that has a higher degree of stability. This is no different to the architecture of muscles. The work of Lieber and Fridén (6) demonstrates the notion that large degrees of physiological cross-sectional area (PCSA) dictates strength, and that FL dictates excursion or speed of contraction. The architecture of the ST muscle-tendon unit MTU) is that it displays long fascicles, has a limited amount of tendon slack, has a long distal free tendon, and is primarily made up of type 2 (fast twitch) muscle fibres (8–11)

There is a saying, 'that methods are many but principles are few', and in muscle the following is true. At a microscopic level, the force-velocity properties of a single sarcomere follows the Hill's muscle model (12) as demonstrated in figure 1. This in combination with the length-tension relationship of a muscle (13) explains how much force a muscle can produce at varying speeds and lengths. These are dependent on PCSA and FL. As described the ST has relatively long FL's and hence has the ability to produce close to its maximum amount of force over a longer length and at increased speeds of contraction. Therefore, by further increasing the FL (theoretically increasing the number of sarcomeres in series) it could be hypothesized that the efficiency of the muscle could be improved.

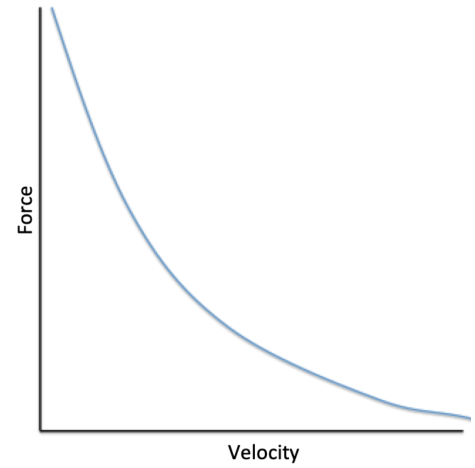

Fig. 1. Force-velocity curve

Role of Semitendinosus in Sprinting

With biceps femoris being the most commonly injured hamstring muscle (14) and with so much talk about biceps femoris activation versus others, the role and importance of ST in sprinting is less discussed. But just like the Cinderella story, ST, the long slender and potentially more lyrical sister may be as important. The seminal work by Chumanov et al. (15) is often referenced for the biceps femoris exponential increase in work done as speed increases to it's maximum. However, many often fail to mention how hard the ST works in compari-

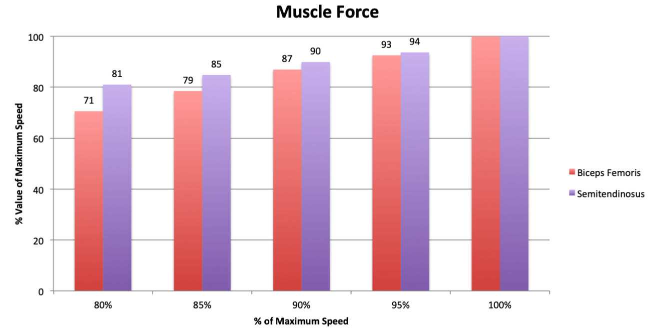

Fig. 2. ST and BF muscle force during incremental running speed. Adapted from Chumanov et al. (15)

son to its maximum force output at other sub-maximal speeds (Figure 2.)

Higashihara et al. (16) has demonstrated that the excitation level of ST is greater than biceps femoris long head (BFlh) at all points except at early stance and late swing during sprinting. This may suggest the ST's ability to work over a large range and at varied lengths. Compared to slower speeds, the ST contribution to negative work disproportionally increases during the mid swing phase as speed increases (17). It's role may be to help control hip flexion but predominantly knee extension during the swing phase of sprinting, reducing the load on the BFlh. The timing of its peak activation supports this. The ST reaches its peak EMG activity earlier than the BF in sprinting and occurs roughly around the point of inflection, where the shank starts to decelerate as it extends in terminal swing (16). It is at this highest EMG activity where the muscle fibres are likely working isometrically with its long distal tendon undergoing lengthening to act as an elastic spring (20). This is further supported as the ST distal tendon is able to undergo greater tendon strain throughout all knee flexion angles compared to the BFlh (21). This adds further support to the suggested MTU function during high-speed movements that would allow greater efficiency as it utilizes the stretch-shortening cycle (SSC).

Synergistic Nature of ST

A higher strength capacity often lends itself to a higher endurance capacity. The analogy of person A, who is able to lift 100kg once versus person B, who is able to lift 50kg once will likely lead to the ability of the person A to be able to lift 30kg many more times than person B. This analogy is the same for the hamstrings. Schuermans et al. (19) showed those with a previous history of hamstring injuries had a reduced ability in the ST to be able to off-load the BF. In line with these facts, ST peak absorption power is produced before all other muscles (19). This adds weight to the theory of a fatigue-based model of BF injuries in conjunction with an inability of its synergists to work optimally.

It is acknowledged that some research prescription may not be directly applicable in the 'real-world' for those sports that require sprinting (1). However, it could be hypothesized that with high volume prescriptions as previously recommended, improvements may come not only from increased strength levels, but also due to increases in the metabolic capacity of the muscle. As discussed, this becomes important in helping to ensure the BFlh does not become overloaded and provides a high level of conditioning to the ST. Therefore NHC's may have the ability to provide different adaptations dependent on training volume.

ST hypertrophy changes in Elite Sprinters

If one was to assess the potential muscular adaptations that sprinting may cause, then it may be reasonable to investigate elite level sprinters. Thankfully this has previously been conducted on collegiate level athletes. The results demonstrate that the ST is the most hypertrophied muscle compared to controls (23). This may not be a surprise when considering its structure and function.

Whether it's sprinting or the exercises chosen in an athlete's strength and conditioning program that elicits the hypertrophic change to ST is unclear. However, what is known is that performing supramaximal eccentric knee dominant exercise leads to hypertrophic changes exclusive to biceps femoris short head and ST (24). The NHC would fit into this category of exercises.

Combine the hypertrophy observed in sprinters and the likely increase in PCSA, you have a muscle that can work at speed and at varying lengths with more strength. Additionally, as described earlier that the tendon of ST is long and with improved strength capacity, it is possible that the ability to utilise the SSC may be further enhanced, improving the ability to work elastically and ultimately more efficiently (25).

Nordics Activation and Adaptations

During sprinting the angular velocity of the thigh and shank need to be controlled. This is demonstrated by the increase in myokinetic demands of both the hip and knee musculature due to the increase in angular velocities (26, 27,28). The hamstrings' ability to control the shank's angular velocity is imperative and is one reason why NHC's may help in hamstring injury rate reduction. As shown by a number of authors, the medial hamstrings have a higher degree of EMG activity during the NHC compared with other commonly prescribed exercises (29,30). However, it should be noted that this is also the same exercise that produces the highest EMG readings for the BFlh (29). The levels of activation of ST are higher than the BF in the initial phases of the NHC (31). This aligns with the higher moment arm at the knee in these ranges and its ability to generate and transfer force in the shortened position (Wrentenberg 1996). This may provide further reason to the resultant adaptations on the ST following NHC's.

The benefits of strength and fascicle length adaptations are not only limited to the BFlh and are likely to be achieved for ST with low volumes if supramaximal loads are utilised (32–34). As described earlier, this is advantageous to muscle function as it expands its length-tension relationship capabilities.

Are Nordics Functional?

As alluded to in the introduction, it has been argued by some that NHC's are 'non-functional' in nature. A question that

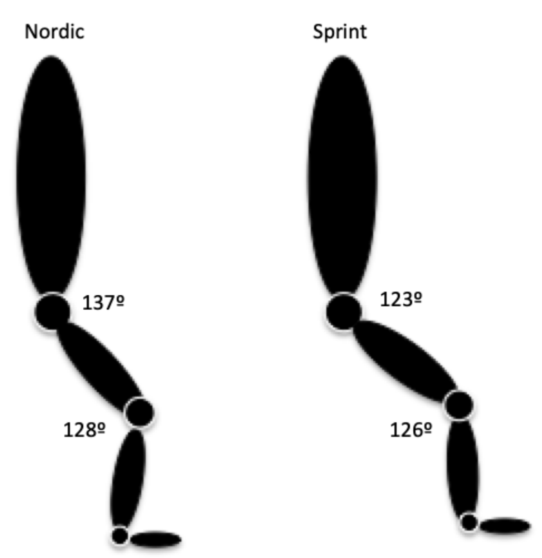

Fig. 3. Angles at maximal EMG activity. Adapted from van den Tillaar (31)

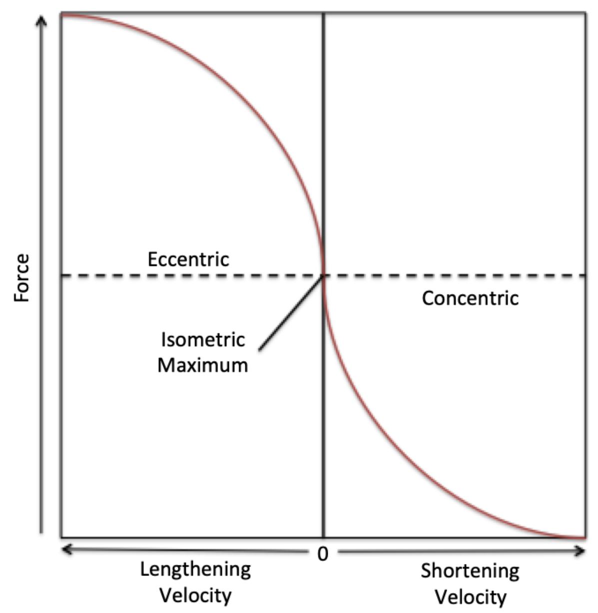

Fig. 4. Force velocity curve of eccentric and concentric muscle action

needs to be asked though is what makes something functional or non-functional? Is it because it's a closed chain exercise? However, many of our exercises are closed chain. Is it because it doesn't resemble the positions of running? A counter-argument is the work performed by van den Tillaar et al. (31) who demonstrated the commonality between the timing of max EMG levels during sprinting and the NHC during its lengthening contraction.

Connective Tissue and Eccentric Exercise

The majority, if not all muscle injuries involve the non-contractile tissue (36). If all injuries involve the non-contractile tissue (connective tissue), then the integrity and health of this vast structure is imperative. It is believed that if the connective tissue stiffness is greater than that of the active muscle system, when under excessive loads the connective tissue is taken beyond its strain capability leading to subsequent tissue failure (37). Hence the interaction between the muscular system and the integrity of the connective tissue system is vital. Therefore, a way to improve the maximal strength qualities of the contractile system is to provide high intensity load - which eccentric contractions can produce (Figure 4.). Eccentric loading also places a large strain on the passive tissue that can lead to adaptation. It has been described that performing eccentric exercise causes shear forces that help to reduce the cross-links formed and may improve the balance between compliance and stiffness within the connective tissue system (37). Furthermore, eccentric overload provides a greater collagen synthesis response, improving the integrity and health of the connective tissue (38). In addition to these structural changes, eccentric contractions offer a different neuromuscular response compared to isometric or concentric contractions, ultimately influencing the tail end of the length-tension curve (39). Therefore NHC's, if performed at an adequate intensity, can have both an effect on the muscle, connective and neural pathways.

Counter-Acknowledgement

Although providing a complete counter-argument against the use of the NHC is beyond this article, it would be wise to make note of some limitations to performing NHC's. In some athletes, posterior knee may occur, limiting their willingness to participate and work at the desired intensity. DOMS is also associated with eccentric exercise. In those unaccustomed to the NHC, DOMS may be a negative bi-product and appropriate programming is required (2). As previously discussed, the adaptations following NHC's may be dependent on volume, indicating that other exercises with the right intensity and volume may achieve similar outcomes. Hence starting with the goal in mind of what adaptation is required i.e. strength, hypertrophy or metabolic capacity, is firstly recommended and then choosing the appropriate exercise is subsequent after.

Conclusion

An often-neglected muscle in hamstring injury prevention and rehabilitation, the ST has been shown to be an important piece of the hamstring health puzzle. Furthermore for those that have still questioned the efficacy of the NHC, the points that have been discussed have hopefully touched on your analytical, critical, theoretical and biomechanical mind. The use of NHC is not a cure, but can form an aspect in achieving a hamstring health solution.

Practical Applications

- ST is a key a key synergist for BFlh. It's function has implications for hamstring injury prevention and injury rehabilitation.
- Strength and architectural changes can occur with low volume NHC's
- NHC's are **one** exercise choice that may allow eccentric (supramaximal) loads to be achieved that positively influences all hamstring muscles and their non-contractile tissue.

Conflicts of Interest

There are no conflicts of interest

References

1. Petersen J, Thorborg K, Nielsen MB, Budtz-Jørgensen E, Hölmich P. Preventive effect of eccentric training on acute hamstring injuries in men's soccer: a cluster-randomized controlled trial. Am J Sports Med. 2011 Nov;39(11):2296–303.
2. Serinken MA, Gençoğlu C, Kayatekin BM. The effect of eccentric exercise-induced delayed-onset muscle soreness on positioning sense and shooting percentage in wheelchair basketball players. Balk Med J. 2013 Dec;30(4):382–6.
3. Dyk N van, Behan FP, Whiteley R. Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: a systematic review and meta-analysis of 8459 athletes. Br J Sports Med. 2019 Feb 26;bjsports-2018-100045.
4. Bourne MN, Opar DA, Williams MD, Shield AJ. Eccentric Knee Flexor Strength and Risk of Hamstring Injuries in Rugby Union: A Prospective Study. Am J Sports Med. 2015 Nov 1;43(11):2663–70.
5. Opar DA, Williams MD, Timmins RG, Hickey J, Duhig SJ, Shield AJ. Eccentric hamstring strength and hamstring injury risk in Australian footballers. Med Sci Sports Exerc. 2015 Apr;47(4):857–65.

6. Timmins RG, Bourne MN, Shield AJ, Williams MD, Lorenzen C, Opar DA. Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): a prospective cohort study. Br J Sports Med. 2016 Dec;50(24):1524–35.
7. Lieber RL, Fridén J. Clinical significance of skeletal muscle architecture. Clin Orthop. 2001 Feb;(383):140–51.
8. Dingboom EG, van Oudheusden H, Eizema K, Weijs WA. Changes in fibre type composition of gluteus medius and semitendinosus muscles of Dutch Warmblood foals and the effect of exercise during the first year postpartum. Equine Vet J. 2002 Mar;34(2):177–83.
9. Torry MR, Schenker ML, Martin HD, Hogoboom D, Philippon MJ. Neuromuscular hip biomechanics and pathology in the athlete. Clin Sports Med. 2006 Apr;25(2):179–97, vii.
10. Ward SR, Eng CM, Smallwood LH, Lieber RL. Are current measurements of lower extremity muscle architecture accurate? Clin Orthop. 2009 Apr;467(4):1074–82.
11. Woodley SJ, Mercer SR. Hamstring muscles: architecture and innervation. Cells Tissues Organs. 2005;179(3):125–41.
12. Hill Archibald Vivian. The heat of shortening and the dynamic constants of muscle. Proc R Soc Lond Ser B - Biol Sci. 1938 Oct 10;126(843):136–95.
13. Gordon AM, Huxley AF, Julian FJ. The variation in isometric tension with sarcomere length in vertebrate muscle fibres. J Physiol. 1966 May;184(1):170–92.
14. Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). Am J Sports Med. 2011 Jun;39(6):1226–32.
15. Chumanov ES, Heiderscheit BC, Thelen DG. The effect of speed and influence of individual muscles on hamstring mechanics during the swing phase of sprinting. J Biomech. 2007;40(16):3555–62.
16. Higashihara A, Nagano Y, Ono T, Fukubayashi T. Differences in hamstring activation characteristics between the acceleration and maximum-speed phases of sprinting. J Sports Sci. 2018 Jun;36(12):1313–8.
17. Chumanov ES, Heiderscheit BC, Thelen DG. Hamstring musculotendon dynamics during stance and swing phases of high-speed running. Med Sci Sports Exerc. 2011 Mar;43(3):525–32.
18. Higashihara A, Nagano Y, Ono T, Fukubayashi T. Relationship between the peak time of hamstring stretch and activation during sprinting. Eur J Sport Sci. 2016;16(1):36–41.
19. Schache AG, Dorn TW, Blanch PD, Brown NAT, Pandy MG. Mechanics of the human hamstring muscles during sprinting. Med Sci Sports Exerc. 2012 Apr;44(4):647–58.
20. Ishikawa M, Komi PV. Muscle fascicle and tendon behavior during human locomotion revisited. Exerc Sport Sci Rev. 2008 Oct;36(4):193–9.
21. Kellis E. Biceps femoris and semitendinosus tendon/aponeurosis strain during passive and active (isometric) conditions. J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol. 2016 Feb;26:111–9.
22. Schuermans J, Van Tiggelen D, Danneels L, Witvrouw E. Biceps femoris and semitendinosus–teammates or competitors? New insights into hamstring injury mechanisms in male football players: a muscle functional MRI study. Br J Sports Med. 2014 Dec;48(22):1599–606.
23. Handsfield GG, Knaus KR, Fiorentino NM, Meyer CH, Hart JM, Blemker SS. Adding muscle where you need it: nonuniform hypertrophy patterns in elite sprinters. Scand J Med Sci Sports. 2017 Oct;27(10):1050–60.
24. Kubota J, Ono T, Araki M, Torii S, Okuwaki T, Fukubayashi T. Non-uniform changes in magnetic resonance measurements of the semitendinosus muscle following intensive eccentric exercise. Eur J Appl Physiol. 2007 Dec;101(6):713–20.
25. Muraoka T, Muramatsu T, Fukunaga T, Kanehisa H. Elastic properties of human Achilles tendon are correlated to muscle strength. J Appl Physiol Bethesda Md 1985. 2005 Aug;99(2):665–9.
26. Dorn TW, Schache AG, Pandy MG. Muscular strategy shift in human running: dependence of running speed on hip and ankle muscle performance. J Exp Biol. 2012 Jun 1;215(Pt 11):1944–56.
27. Mann R, Murphy A. The Mechanics of Sprinting and Hurdling. 2018th ed. Ralph Mann;
28. Sun Y, Wei S, Zhong Y, Fu W, Li L, Liu Y. How Joint Torques Affect Hamstring Injury Risk in Sprinting Swing–Stance Transition. Med Sci Sports Exerc. 2015 Feb;47(2):373–80.
29. Bourne MN, Williams MD, Opar DA, Al Najjar A, Kerr GK, Shield AJ. Impact of exercise selection on hamstring muscle activation. Br J Sports Med. 2017 Jul;51(13):1021–8.
30. Tsaklis P, Malliaropoulos N, Mendiguchia J, Korakakis V, Tsapralis K, Pyne D, et al. Muscle and intensity based hamstring exercise classification in elite female track and field athletes: implications for exercise selection during rehabilitation. Open Access J Sports Med. 2015 Jun 26;6:209–17.
31. Hegyi A, Lahti J, Giacomo J-P, Gerus P, Cronin NJ, Morin J-B. Impact of Hip Flexion Angle on Unilateral and Bilateral Nordic Hamstring Exercise Torque and High-Density Electromyography Activity. J Orthop Sports Phys Ther. 2019 Aug;49(8):584–92.
32. Bourne MN, Duhig SJ, Timmins RG, Williams MD, Opar DA, Al Najjar A, et al. Impact of the Nordic hamstring and hip extension exercises on hamstring architecture and morphology: implications for injury prevention. Br J Sports Med. 2017 Mar;51(5):469–77.
33. Lacome M, Avrillon S, Cholley Y, Simpson BM, Guilhem G, Buchheit M. Hamstring Eccentric Strengthening Program: Does Training Volume Matter? Int J Sports Physiol Perform. 2019 Apr 29;1–27.
34. Presland JD, Timmins RG, Bourne MN, Williams MD, Opar DA. The effect of Nordic hamstring exercise training volume on biceps femoris long head architectural adaptation. Scand J Med Sci Sports. 2018 Jul;28(7):1775–83.
35. van den Tillaar R, Solheim JAB, Bencke J. COMPARISON OF HAMSTRING MUSCLE ACTIVATION DURING HIGH-SPEED RUNNING AND VARIOUS HAMSTRING STRENGTHENING EXERCISES. Int J Sports Phys Ther. 2017 Oct;12(5):718–27.
36. Tidball JG, Salem G, Zernicke R. Site and mechanical conditions for failure of skeletal muscle in experimental strain injuries. J Appl Physiol Bethesda Md 1985. 1993 Mar;74(3):1280–6.
37. Baar K. Minimizing Injury and Maximizing Return to Play: Lessons from Engineered Ligaments. Sports Med Auckl NZ. 2017 Mar;47(Suppl 1):5–11.
38. Heinemeier KM, Olesen JL, Haddad F, Langberg H, Kjaer M, Baldwin KM, et al. Expression of collagen and related growth factors in rat tendon and skeletal muscle in response to specific contraction types. J Physiol. 2007 Aug 1;582(Pt 3):1303–16.
39. Kaminski TW, Wabbersen CV, Murphy RM. Concentric versus enhanced eccentric hamstring strength training: clinical implications. J Athl Train. 1998 Jul;33(3):216–21.